"TEAM Z," A RAPID REACTION APPROACH TO MISSION OPERATIONS SYSTEM DESIGN AND COSTING

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ABSTRACT

A mission operations system (MOS) comprises a host of functions in a variety of disciplines, including telecommunications, orbit determination, spacecraft and ground system evaluation, data processing, data transport, mission design, event sequencing, facility and spacecraft scheduling, and test and integration. Combining these into a system design has typically been a sequential process. Multiple iterations are required as uncertainties and conflicts are slowly discovered in the combinatorial numbers that result from multiple interfaces. This approach demonstrably produces good designs and accurate cost estimates, but it is inherently slow and expensive. With proposal and mission activity at an all time high, the sequential process begins to break down, becoming a bottleneck to efficient planning.

The Telecommunications and Mission Operations Directorate (TMOD) of NASA's Jet Propulsion Laboratory (JPL) is adopting a collaborative approach to MOS design and costing. Called "Team Z," this approach is potentially applicable to all phases of a mission, from formulation to operations, but has been tested thus far on proposal efforts only. An extensive questionnaire has been developed which is given to the client project or proposal team prior to a Team Z session. The client delivers the questionnaire to the team for members' individual evaluation. Then the team and the client meet for two to three hours in JPL's Project Design Center (PDC), a room equipped with software and hardware tools that enable efficient collaboration. The joint session allows questions of clarification by both parties and proceeds to examine the operations concept in a detail appropriate to the project's development phase. Costing is done in real time, allowing the client and the team to consider the effects of options and tradeoffs. A draft report is completed by the end of the session. Within days the final report is prepared, vetted and delivered to the client, embodying a commitment by TMOD. The team works rapidly, costs accurately, and finds greater opportunity to identify and perform cost-effective tradeoffs.

This paper describes the team, its purpose, process, tools, status, and plans.

INTRODUCTION

In the last decade, NASA's approach to deep space exploration has undergone a sea change. From the rare launch of mighty spacecraft, we have transitioned to launches of a few small spacecraft each year. Figure 1 effectively portrays this massive alteration in exploration approach. At the same time, NASA has declared that its mission operations costs must be drastically cut in both absolute and relative (i.e., per mission) terms. JPL, with a major responsibility for deep space operations, has been faced with a puzzle: how do we operate, or assist in the operation of, an order of magnitude more spacecraft with a fraction of the money?

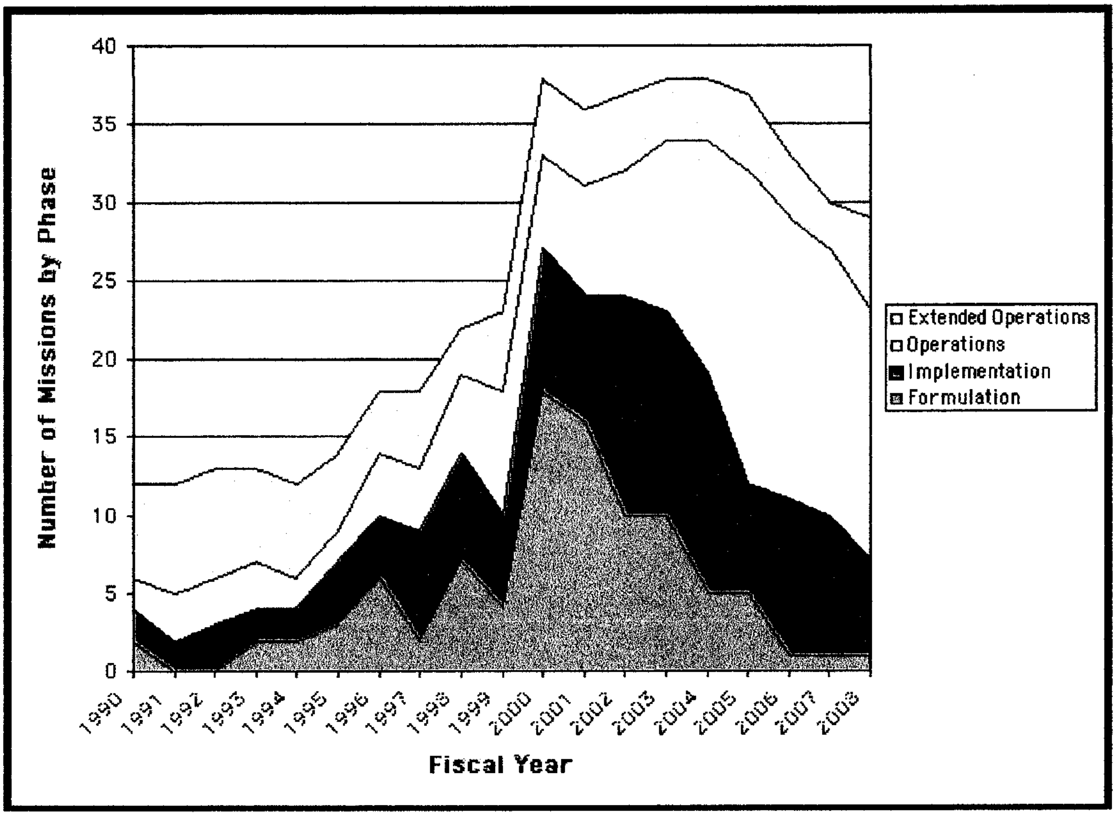

Figure 1. Number of Deep Space Missions by Phase[1]

(Note: The drop in future mission numbers in each phase is an artifact of the planning process.)

This problem has been tackled in several ways. The Deep Space Network (DSN) comprises eleven massive antennas (34 and 70 meters in diameter) located at three sites separated by about 120 degrees of longitude. By virtue of its capital expense, the DSN has been almost mission-independent for most of its history. This is not true of the data-handling systems that receive raw data from the DSN. In 1989, JPL departed from its tradition of project-specific mission operations systems, to develop a ground system for multiple users, the AMMOS, Advanced Multi-Mission Operations System. This system limited mission-peculiar ground system modifications to a fraction of their former cost and provided missions with financial incentives to avoid using their own ground data systems.

NASA as a whole has changed its operations approach,[2] adopting a "service" paradigm, wherein missions order quantities of services rather than specific tools for their own application. Multi-mission systems and the service paradigm have addressed the mission-operations cost puzzle to a large extent, but because of the huge environmental variance within which deep space missions must operate, there still must be mission-specific adaptations to these systems and services. A Mission Operations System (MOS) must be devised for each proposed mission and because there are many more proposals than there are approved missions, this has been a lengthy, labor-intensive task.

THE MISSION OPERATIONS SYSTEM

Conceptually, an MOS comprises the people, procedures, and equipment necessary to utilize a spacecraft to accomplish the goals of its mission. Various degrees of automation on the ground and on the spacecraft permit tradeoffs between the number of people and the amount of equipment required for the MOS, but in all cases there are a large set of procedures to be exercised. JPL's Telecommunications and Mission Operations Directorate (TMOD) has created a taxonomy of "services" that include most of the procedures required in an MOS. Table 1, reproduced from *NASA's Mission Operations and Communications Services - AO 00-OSS-XX*,[3] lists the standard services offered for deep space missions. Some, such as Telemetry Services, are always used, others, such as Radio Astronomy Services, are seldom, if ever used for spacecraft missions and are mostly provided for other users of the DSN.

Table 1. Standard TMOD Services

Service Types	Brief Description
Command:	
Command Radiation	RF modulate and transmit CLTUs to user spacecraft.
End-to-End Command Delivery	Error-free delivery of command files to spacecraft using COP-1 protocol.
Telemetry:	
Frame	Provides frame reconstruction and routing options for CCSDS compliant formats.
Packet	Extracts packets from frames by earth received time or sequence number.
Channel	Extracts data samples from packets based upon pre-established criteria.
Data Set	Provides Level-0 products for selected instruments and observation cycles.
Mission Data Management:	
Short Term Data Retention	Data buffering and staging (up to 1-week) to ensure delivery.
Long Term Data Repository	Data storage and retrieval for life-of-mission.
Archive Product Preparation	Prepares data products for long-term data archival.
Experiment Data Products:	
Level 1 processing	Generates Level-1 experiment data.
Higher Level Processing	Generates Level-2 (or higher level) data products.
Photo Products	Provides photo product enhancement and annotation at any level.
Science Visualization	Data visualization and animation using navigation, ephemeris, CAD, and remotely sensed data/imagery. 3D science data rendering and animation. Sense of Active Presence – virtual reality based on telemetry, science data, models, etc.
Tracking and Navigation:	
Radio Metric Measurement	Provides raw, uncalibrated radio metric observables.
Validated Radio Metric Data	Validated, calibrated, radio metric data.
Orbit Determination	State vectors representing a solution obtained from conditioned data.
Trajectory Analysis	Flight path prediction, reconstruction, or optimization.
Maneuver Plan/Design	Provides maneuver analysis and design required for project planning.
Ephemeridies	Ephemerides for planets, planetary satellites, comets and asteroids.
Modeling & Calibration	Provides terrestrial frame and transmission media calibrated data.
Gravity Modeling	Harmonic gravity models for Moon, Mars, and Venus.
Cartograpphy	Cartographic anchor points on surface of specific bodies
Flight Engineering:	
Spacecraft Health/Safety Monitor	Monitoring of spacecraft health based on project-provided limits automated alarms.
Spacecraft Performance Analysis	Provides system level performance analysis of spacecraft.
Telecom Link Analysis	Planning, prediction, and performance analysis of spacecraft telecommunications link.
Spacecraft Time Correlation	Monitors S/C clock drift and correlates S/C time to a standard time reference.
Instrument Health/Safety Monitor	Provides instrument performance monitoring based on project-provided limits.
Sequence Engineering	Design, development, and execution of uplink process.
Science Observation Planning	Design and integration of target observations producing conflict-free timeline.
Radio Science:	
Baseband measurements	Transmission S-, X-, and K_a-Bands, open and closed-loop signal capture.
Power Spectrum Display	Capture and partitioning of received signal into frequency bins containing amplitude.
VLBI:	
Narrowband Measurements	Signal delay to two or more antennas based on narrowband signal.
Wideband Measurements	Signal delay to two or more antennas based on wideband signal.
Radio Astronomy:	
Radio Astronomy in DSN Bands	IF signal distribution at 2, 8, and 32 GHz to special purpose equipment.
Radio Astronomy at Special Freqs.	IF signal distribution at special frequencies from 70-meter R & D cone.
Radar Science:	
Continuous Wave	Transmission and reception of reflected continuous wave (CW) signal.
Binary Phase Coded	Transmission and reception of reflected CW signal modulated with binary sequence.
Interferometric Observations	Transmission and reception of reflected CW signal at multiple sites.
Ground Communications:	
Ground Network	Provides data, voice, and video communications network services.
Data Transport	Low-latency UDP or Reliable Network Service (RNS), guaranteeing no lost packets.
Collaborative	Distributed file or computing services or videoconferencing between specific sites.

The way in which these procedures are implemented, whether by hardware, software, or people, and the way in which they are integrated constitutes the MOS.

MOS DESIGN, THE OLD WAY

As Fordyce points out:[4]

> "Until recently, activities have centered on a relatively small number of unique, first-of-a-kind projects, and most of the mission analysis software was created on an as needed basis by mission design engineers to solve their immediate problems. Because of the unique nature of each mission, little thought was given to reuse by subsequent projects."

With the exception of the "big iron" of the DSN, the same could be said of the most of the other components of the mission operations systems of "the old days." Each mission designed its own MOS. The extent of inheritance was determined by the designers in each discipline of the system, who would often reuse pieces of previous systems. Since there were so many "firsts" and so few missions, this was a rational and cost-effective approach for the time, but it was slow and error prone.

Several recent changes have conspired to make this approach obsolete.

1. More missions. In "the old days," new missions appeared at intervals of three years or more. That interval is now closer to three months.

2. Small numbers of instruments on smaller spacecraft. On our first visits to the bodies and environments of the solar system, our knowledge was very scanty and our trips rare. Hence, each spacecraft was outfitted with multiple instruments to gather data in numerous domains during these occasional opportunities. The knowledge gained in those first visits permits us to attempt more focused missions, with fewer instruments. This, plus vast improvements in miniaturization has the concomitant effect that we can use smaller, cheaper spacecraft, and send more of them. Serendipitously, this also lowers the pressure to send multiple instruments on a single spacecraft and in fact can sometimes augment the returned results by spatial distribution of instruments.

3. Standardization of spacecraft. Because we are developing more spacecraft for deep space missions, we can reap an economy of scale by having common systems and common buses.

4. Standardization of data transmission and transport. Vast improvements in telecommunications efficiency were available in the early days of deep space exploration. They were enabled by research and technology. Now we can operate close to the theoretical limits of channel capacity. In addition, the international involvement in deep space has become more collaborative than competitive. As a result, we have standardized on frequencies, codes, and data transport formats with little or no loss in communications efficiency.

5. Cheap, powerful computers, standardized operating systems, and cheap terrestrial bandwidth. In "the old days," the computers of the MOS and their operation represented a major fraction of the operations cost. In addition, the adoption of the next generation of these devices often entailed completely rewriting the software. Transmission of data between computers was slow and expensive, so that centralized systems were required. We brought the people to the system at great expense and with substantial dislocation. Today, computer hardware is a minor expense, data can be sent between computers cheaply and at great speed, and upgrades to operating systems, particularly UNIX, are far less painful than they once were.

6. Methodologies for collaborative engineering. Finally, modern tools have enabled groups of engineers to share their ideas much more quickly and completely than in the past. Using tools variously known as "groupware," or "computer-supported, collaborative work" (CSCW), engineers can design and cost systems with a high degree of complexity almost in real-time, supported by the design software of their discipline.

THE PROJECT DESIGN CENTER AND "TEAM X"

Most of the above changes were applicable to and had a more immediate impact for commercial products, including earth satellites. In 1993, a group of JPL people visited nascent concurrent engineering sites at a number of aerospace firms. They returned determined to develop such a site for the purpose of deep space spacecraft design. It opened in June of 1994 as the Project Design Center, or PDC. Jeffrey L. Smith describes it as:

> "The PDC provides a facility, with multiple rooms, for design teams to use to conduct concurrent engineering sessions. It provides all the equipment needed by teams for these design sessions, including computers, projectors, audio/video conferencing, network connections, etc. It also provides the software needed by the design teams—both COTS and custom developed."[5]

He also notes that:

> "The principle lesson learned is that improving the productivity of design teams requires improvements to the processes those teams employ and the processes that support those teams, not simply or primarily the introduction and use of 'better' software tools or models."

One of the first and continuing uses of the PDC is its application to preparing proposals for new missions by "Team X." Team X, or the Advanced Products Development Team is a real-time spacecraft design team with representatives from each of the relevant design disciplines. Engineers take full-time assignments to the team for a nominal two years. This allows a true team spirit to be developed while assuring maintenance of engineering skills by the members.

TEAM Z

TMOD has been moving to a true multi-mission system for many years. Applying a service paradigm to its offerings permits more rapid and accurate costing of mission operations then was previously possible because the services are well defined and the costs are incremental. However, the TMOD process for designing and costing an MOS was sequential, confined to organizational stovepipes, and extremely demanding of the time of both the mission and TMOD managers. Typically the mission's MOS manager would meet with each Service System Manager (SSM)—one of the eight TMOD people responsible for a subset of the TMOD services—to negotiate a set of services and a price. As the MOS manager went to each SSM, he or she would be continually developing the mission concept, so that when the entire set of SSMs had been consulted, iteration with each would be necessary. Indeed, as this process took place over the weeks, the spacecraft design would also be changing, invalidating some of the MOS manager's negotiations. Finally, some sort of design and estimate would be concluded. Besides the time and effort required, there were three other shortcomings in the process. First, there was no good way to conduct tradeoffs between the services save by suggestions by one SSM that would then have to be taken to the others individually. Second, there was no good record of the assumptions behind the estimate. Third, the MOS manager emerged with what he or she thought was a commitment, though officially there was none until much later, when a service agreement was signed. This process resulted in MOS system designs, but much misunderstanding and distrust. The situation was exacerbated by the increased proposal activity and NASA's demand for proposers to submit cost *commitments*, and not just estimates.

In late 1998, Richard P. Mathison, TMOD's Chief Engineer suggested that TMOD create a team on the order of Team X for developing MOS designs and costs. This became known as "Team Z," the Rapid Response Team for MOS Design and Costing.

THE TEAM Z APPROACH

Personnel

Each of the SSMs provides one or more trusted design engineers to the team: specifically, the people who would in any case be involved with costing a mission's needs. The team members and their assignments are shown in Table 2. There are four members who are not appointed by an SSM and are not directly responsible for a service: the facilitator, the documentarian, the MOS Systems Integrator, and the Resource Allocation person.

Table 2. Team Z Membership

Position	Function or Services Covered	Frequency of Involvement
Facilitator	Seeks good and complete communication among members and with mission representatives.	High
Documentarian	Takes notes. Collates and prepares final report.	High
MOS Systems Integrator	Integrates costs and seeks tradeoffs.	High
Antenna & Microwave	None directly. Collects requirements for DSN antenna and microwave modifications.	Low
DSN Science	Radio Science, VLBI, Radio Astronomy, Radar Science	Medium
Flight Engineering	Flight Engineering, Science Observation Planning	High
Instrument Sciences	Experiment Data Products	Medium
Mission Services, Engineering	Sequence Engineering	High
Mission Service, Operations	Sequence Engineering	High
Network Infrastructure	Ground Communications	High
Resource Allocation	None directly. Provides analysis of station availability and aperture costs.	High
Telecommunications & Data Management	Command, Telemetry, Mission Data Management	High
Tracking & Navigation	Tracking and Navigation	High

Tools

The team meets in the PDC. Each member has a workstation available and access to two types of tools. The first are the tools which the individual team member brings to the Center to enable his or her analysis of the mission requirements and resulting service requirements. These tools may be used in real or non-real time as necessary.

The second set of tools are collaborative applications. There are two at present. First is a set of linked spreadsheets. Each team member has provided a cost model in Microsoft® Excel format. These have been implemented in the PDC and each has been linked to all of the others by a publish and subscribe mechanism. The primary use so far is to provide a real-time roll-up mechanism for quick and efficient cost summarization by year and mission phase. An example summary is shown in Figure 2. Any of the spreadsheets can be projected on a large screen for the team and customers' perusal and discussion. Eventually we anticipate more cross-linking of the members' models to facilitate tradeoffs. An example is the relationship between tracking for navigation purposes and telemetry purposes. Aperture cost is a substantial fraction of the mission operations cost. The navigation and telemetry functions are usually performed simultaneously at each antenna. Parameters for the two can sometimes be advantageously adjusted to reduce the tracking time required, resulting in substantial cost savings.

	A	B	C	D	E	F	G	H	I	J	K
1	**EXAMPLE MISSION**										
2	**IMPLEMENTATION PHASE SUMMARY**	**TOTAL**		**FY2001**		**FY2002**		**FY2003**		**FY2004**	
3		**WY**	**$K**	**WY**	**$K**	**WY**	**$K**	**WY**	**$K**	**WY**	**$K**
4	Ground Communications		262.0		0.0		0.0	0.1	131.0	0.1	131.0
5											
6	DSN Radio Science		0.0								
7											
8	Instrument Science	6.9	944.9	1.3	212.5	2.3	393.5	1.6	196.2	0.8	142.7
9											
10	Mission Services and Applications	17.2	2928.4	2.1	345.6	4.7	801.0	5.7	980.3	4.7	801.6
11											
12	Basic MP&A Engr. Support	3.6	638.1	0.3	54.7	1.3	218.8	1.1	200.6	0.9	164.1
13											
14	Basic MS&A Operations Support	4.9	824.5	0.6	102.0	0.6	102.0	2.1	348.5	1.6	272.0
15											
16	FLIGHT ENGINEERING SERVICES	4.5	760.8	0.1	8.5	1.5	250.8	1.5	250.8	1.5	250.8
17											
18	MSAS ADAPTATION	4.2	705.1	1.1	180.4	1.4	229.5	1.1	180.4	0.7	114.8
19											
20	Navigation	3.8	637.5	0.0	0.0	1.3	212.5	1.3	212.5	1.3	212.5
21											
22	Development	3.8	637.5	0.0	0.0	1.3	212.5	1.3	212.5	1.3	212.5
23											
24											
25											
26	Telemetry, Command & Data Mgmt	5.9	985.3	1.0	167.0	2.3	384.1	1.5	250.5	1.1	183.7
27											
28	PROJECT ADAPTATION DEVELOPMENT	5.9	985.3	1.0	167.0	2.3	384.1	1.5	250.5	1.1	183.7
29											
30											
31											
32											
33	TOTAL DIRECT COST	**32.7**	**5758.1**	**4.3**	**725.1**	**10.6**	**1791.1**	**10.1**	**1770.5**	**8.0**	**1471.4**
34											
35	Resource Allocation (DSN Aperture Cost)										
36											
37	TOTALS ATTRIBUTED COST	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
38											
39	GRAND TOTALS	**32.7**	**5758.1**	**4.3**	**725.1**	**10.6**	**1791.1**	**10.1**	**1770.5**	**8.0**	**1471.4**
40		WY	$K	WY	$K	WY	$K	WY	$K	WY	$K
41		TOTALS		FY2001		FY2002		FY2003		FY2004	

Figure 2. Sample Summary Cost Estimate

The second collaborative tool is a report writer. Each team member has a Microsoft® Word template within which the member can prepare a part of the final report. The template includes standard paragraphs which can be modified as required, places for private commentaries and reminders, and places for summaries. When the member saves the work, it is rolled up into the proper section of the overall report. Service-specific paragraphs are placed in the appropriate section, summary materials such as concerns and issues are combined with other members' summary material, private commentaries and reminders remain on the member's workstation. Using this tool, draft and final reports can be prepared in a fraction of the time required by conventional means.

The use of templates in the report writing tool provides a means by which to insure completeness. Preserving a record of assumptions has been a continuing problem in later fulfilling mission commitments. The use of standard language and in-context reminders prevents the omission of important data, including the assumptions upon which the estimates are based. Another aid to keeping this record is embedded in the process followed by the team and its customers.

Process

Figure 3 is a flow chart of the Team Z process. It begins with a request from a mission to assist them with designing and costing an MOS. As the key step in the Team Z process, the mission is asked to fill in, to the extent it can, a lengthy questionnaire. Figure 4 is a sample page from this questionnaire. The extent to which the mission can complete this questionnaire depends upon which development phase it is in. A mission working on its first proposal will be able to answer only a fraction of the questions. A mission approaching launch must be able to answer all of them. Where the mission cannot answer a question, there is often a default answer which the team will use. These defaults are listed on the questionnaire. The questionnaire serves three purposes. First, it alerts the mission as to the kinds of questions it must address in its development. This is especially useful for naive proposers. Second, it efficiently provides the data that the team needs to begin developing an MOS design and cost. Third, it provides a written record of many of the assumptions that go into the MOS design and cost. As such, the mission's questionnaire is included in the final report.

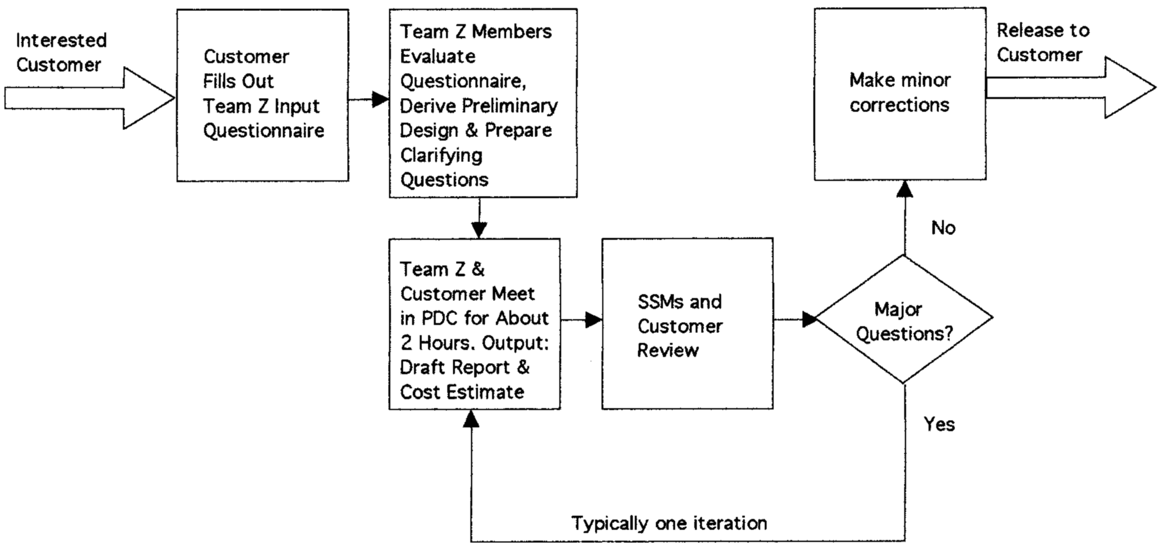

Figure 3. The Team Z Process

The team members evaluate the questionnaire individually, and to the extent possible, they prepare a preliminary design and cost. They also formulate questions of clarification to ask of the mission representative.

A Team Z meeting is then held with the customer. The meeting is in the PDC and lasts for about two hours. The customer gives a brief presentation on the mission and the team members ask their previously prepared questions and any others that come up. Depending on the maturity of the estimates, spreadsheets may be projected for comment. Within hours of the meeting, the documentarian produces a draft report, including a cost estimate. This report is submitted to the mission and to the SSMs for review.

If there are only minor issues, the report is corrected and issued to the customer. If there are major questions, a second Team Z meeting is held, again of about two hours duration. Typically a single iteration is sufficient to allow a final report to be prepared. This report is given to the customer and forms the basis for a formal commitment by the TMOD Director. From the time that Team Z receives the completed questionnaire until a final report is submitted is about one week. Actual working time for each of the Team Z members and their SSM is about five hours. The previous linear process often took several weeks to accomplish.

	A	B	C	D	E	F	G	H	I
1	Requestor (Name):	Telephone:			Mission Name:			What do you want to accomplish with Team Z?	
2	Organization:	Fax:			Current Phase:				
3	Address:	E-mail:			Funding Agency (e.g., NASA, Code SL):				
4									
5									
6									
7	Mission Operations System Questionnaire								
8	Team Z Question	Customer Answer						Default Question or Answer	
9	Mission Description:								
10	Describe your mission. Among the events to consider carefully are flybys, satellite tours, orbit insertions, entries, landings, rendezvous, body orbiting.	Overview:						Is your mission "like" another mission? Which one and in what way?	
11	What solar system bodies will be visited and in what modes? (e.g., flyby, landing, orbiting)								
12	How many spacecraft are involved? Are we planning for a set of spacecraft or just one?							One	
13	Describe any new technologies in your mission.							No.	
14	Mission phases and duration (dates and days) You <u>must</u> supply us with an SpK file. *If you do not know how to do this, please ask. We will be happy to assist you in its preparation. (For this purpose, a mission phase is defined as a length of time over which the tracking requirements*								
15	Identify events and their drivers not included in the SpK file. (i.e., those that are not driven by navigation phase.)								
16	What are the pre-launch events (key milestones)?								
17	Will there be Operational Readiness Tests?							Yes	
18	What are the post-launch events (key milestones)?								
19	Will there be "delayed development" (development during cruise)?							No	
20	Assembly, Test and Launch Operations (ATLO)								
21	Duration (weeks)								
22	Where will ATLO be done?							JPL (SAF) and KSC	
23	Will the integration and test of the flight components use TMOD services or components? Which ones?							Telemetry services.	
24	Will flight operations personnel be involved in day-to-day I&T activities?							Yes.	
25	Do you plan to do end-to-end sequence validation?								
26	DSN compatibility test time requirements								
27	Launch and post-launch checkout								
28	Duration (hours or days)							30 days	
29	Tracking coverage requirements (actual tracking hours per pass, and passes per unit time)							3 eight-hour passes per day	
30	What is your flexibility in tracking scheduling? That is, you can schedule tracking within (unit of time) of my request?	Check one: ☐ minutes		☐ hours		☐ days		Days	
31	What fraction of tracks will have commanding?							100%	
32	What fraction of tracks will have uplink modulation on?							100%	
33	Trajectory control requirements							none	
34	Engineering data rates and data quantity								
35	Science data rates and data quantity								

Figure 4. Team Z Questionnaire Page

Status

Team Z is still a work in progress. Too much time is still required by the SSMs in their review of their team member's results and too often, there have been substantial changes to those results as a result of the review. In each case, however, the team member uses the results of the review to modify his or her cost model, and with each new customer, we expect our results to be more accurate after the first meeting. The goal is to require only a cursory review by the SSM.

When these models display increased fidelity, the team will concentrate on two areas. The members will improve the facility of their tools by linking the PDC models more directly to their support software. More important, the team will take greater advantage of having all of the services represented in the same room, exploring more sophisticated tradeoffs. Even with our current capabilities, however, we were able to save one mission $3,000,000 by identifying an unnecessary overlap in their telemetry and navigation tracking.

FUTURE DIRECTIONS

To date, Team Z has participated only in the early, formulation phase of missions. There is an especially attractive opportunity in this phase, where plans and designs are flexible. Often there is opportunity to create a better *system* answer for NASA by improved matching of the spacecraft and ground capabilities and sometimes even by migrating traditional ground functions to the spacecraft. Team Z can be a catalyst in promoting such changes. This will be particularly viable when NASA implements full-cost accounting.

Team Z is completely capable of participating in the implementation and operations phases as well as the formulation phase. Team Z cannot replace the functions of the traditional MOS Design Team in dealing with the day-to-day issues of developing and operating an MOS. However, it can perform episodic evaluations or reevaluations of MOS conceptual designs when a mission is first designed, when new data become available, or when substantive mission design changes are made, supporting proposals, major reviews, or design trades.

ACKNOWLEDGEMENT

My thanks to Chuck Klose, Chuck Holmes, and Dave Morris for their help in providing the data for Figure 1. The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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[1] Data supplied by J. Charles Klose and David Morris of JPL and Charles Holmes of NASA.

[2] Perkins, Dorothy C., McKinley, Edward L., and O'Neill, John W. (1998). *NASA Recasts its Operations Approach to Reduce Costs.* Proceedings of the Fifth International Symposium on Space Mission Operations and Ground Data Systems, SpaceOps 98, Tokyo, Japan, June 1-5, 1998, paper # 1a001.

[3] *NASA's Mission Operations and Communications Services - AO 00-OSS-XX,* February 2000.

[4] Fordyce, Jess. (1996). *Re-Engineering JPL's Mission Planning Ground System Architecture for Cost Efficient Operations in the 21st Century.* Proceedings of the Fourth International Symposium on Space Mission Operations and Ground Data Systems, SpaceOps 96, Munich, Germany, September 16-20, 1996, paper # SO96.3.15 1.

[5] Smith, Jeffrey L. (1998). *Concurrent Engineering in the Jet Propulsion Laboratory Project Design Center.* Society of Automotive Engineers. 98AMTC-83, June 1998.

CL 00-0786

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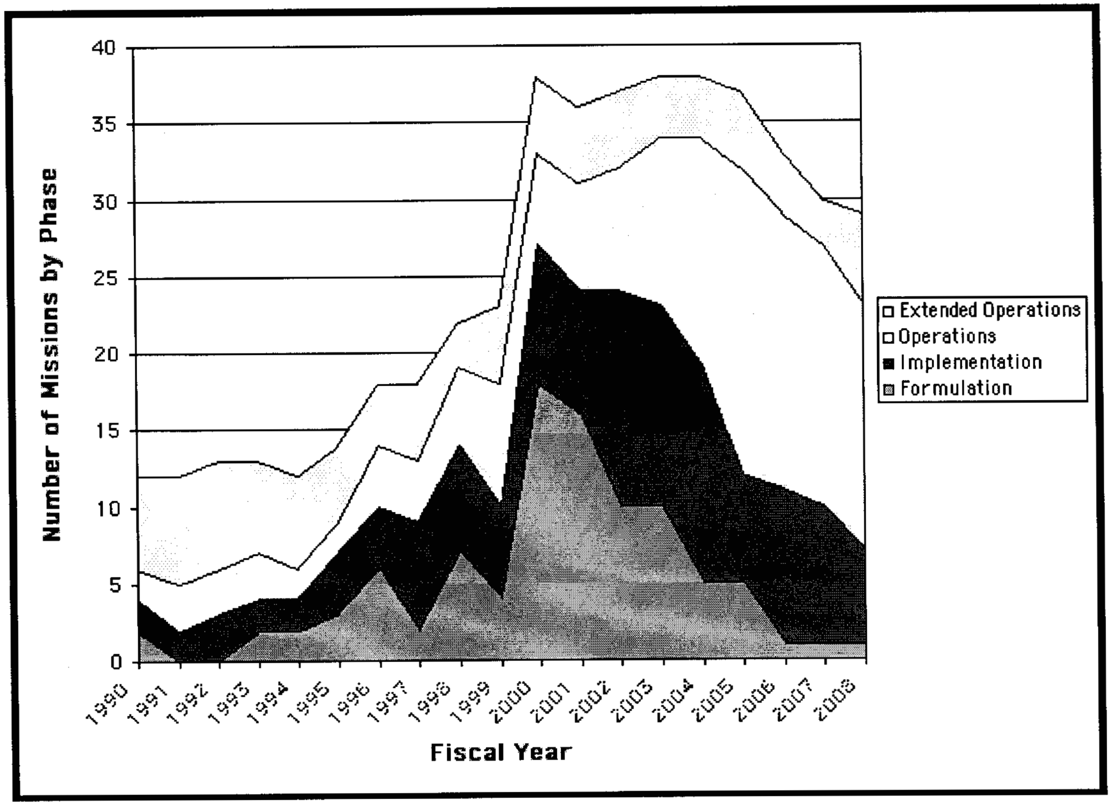
Spaceops 2000
June 19-23, 2000

A Deep Space Mission Operations Paradox

- **More missions, more often**



Note: The drop in future mission numbers in each phase is an artifact of the planning process

- **Less money**

Resolving the Paradox

- "Multi-Mission" systems
  - The Deep Space Network (DSN)

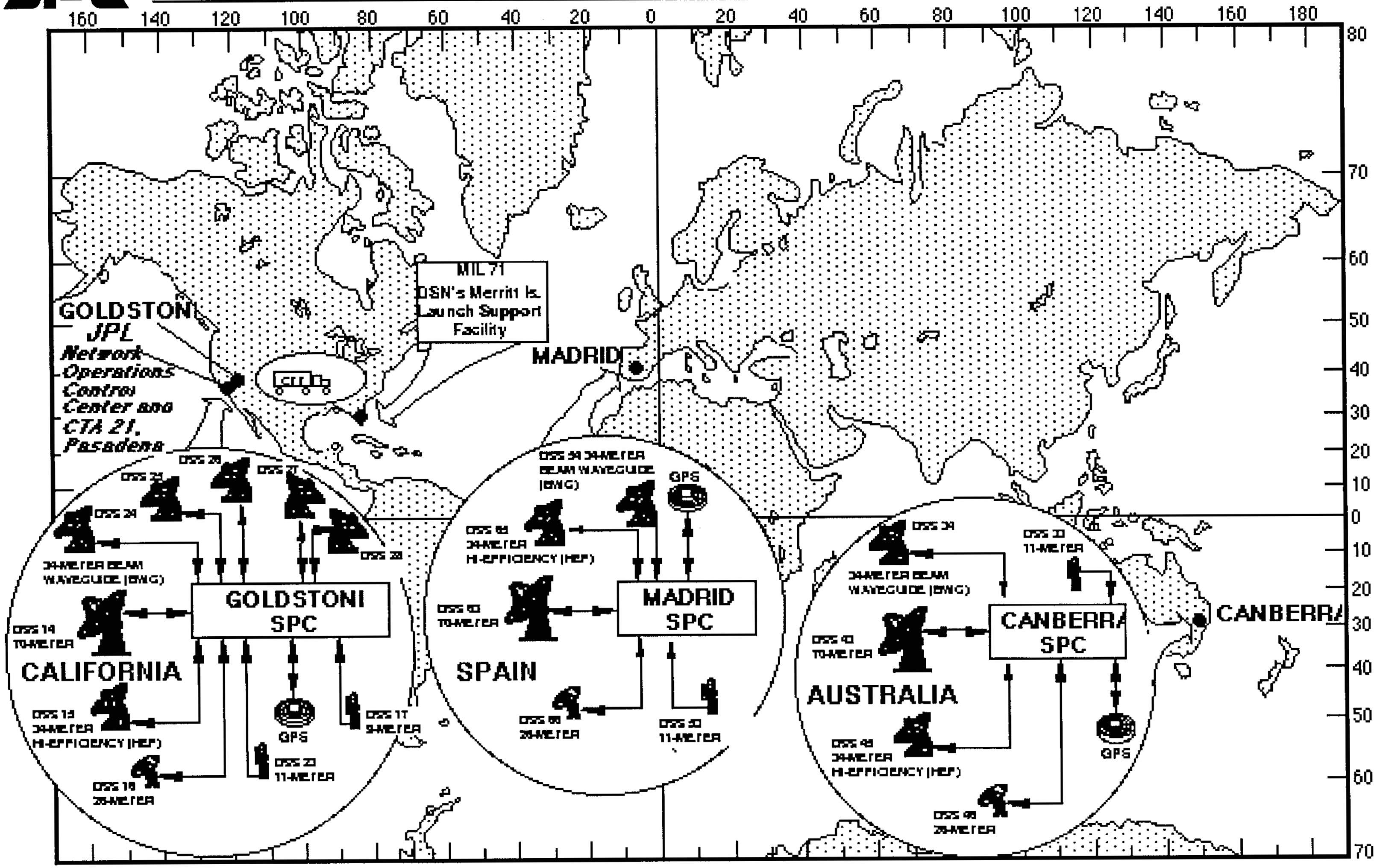
    Little or no adaptation for each mission
  - The Advanced Multi-Mission Operations System (AMMOS)

    Minimal mission-specific adaptation, charged to the project
- The "Services Paradigm"
  - Projects buy services, not tools, permitting:
    - Multi-mission teams
    - Adaptation by application specialists, not mission specialists
    - Base-line funding, incremental adaptation

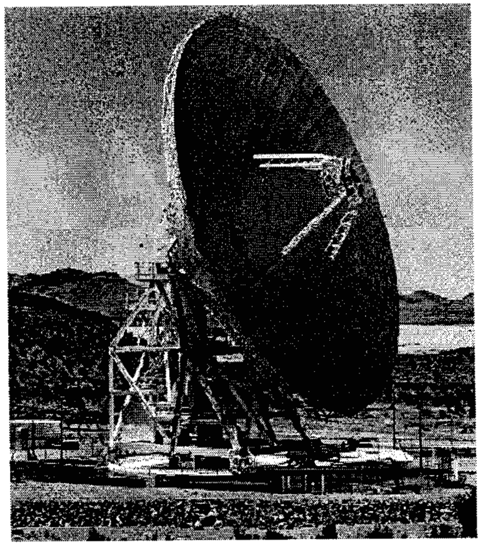
But,

The Deep Space Network: Geography

JPL

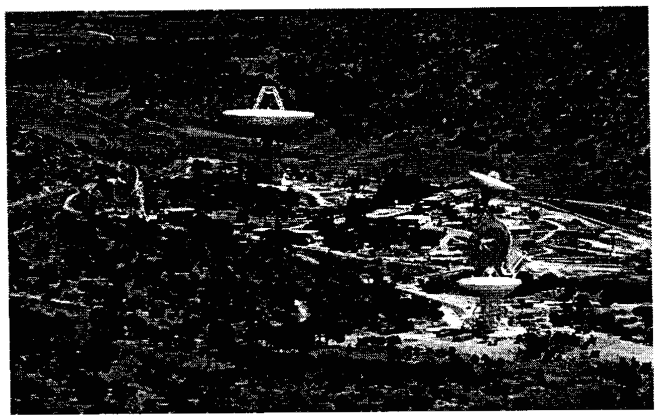


The Deep Space Network: Facilities



34 m Beam Wave Guide Antenna at Goldstone, California

DSN 70 meter Antenna at Canberra, Australia



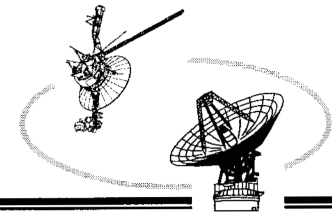
DSN Site near Madrid, Spain

Signal Processing Center (SPC-10)

A Remaining Problem

- Deep space missions are disparate
- A Mission Operations System (MOS) must be designed and costed for each mission proposal
- An MOS comprises many technologies, thus many domain experts must be consulted
- There are many more proposals than there are missions
- Proposals come in bunches, all due at the same time

"Team Z" was proposed as an efficient method of responding to this challenge



What is an MOS?

- An MOS comprises the
  - People
  - Procedures
  - Equipment

  necessary to utilize a spacecraft to accomplish the goals of its mission.

- The services required include:
  - Command
  - Telemetry
  - Mission Data Management
  - Experiment Data Products
  - Tracking and Navigation
  - Flight Engineering
  - Sequence Engineering
  - Science Observation Planning
  - Radio Science
  - Very-Long Baseline Interferometry
  - Ground Communications

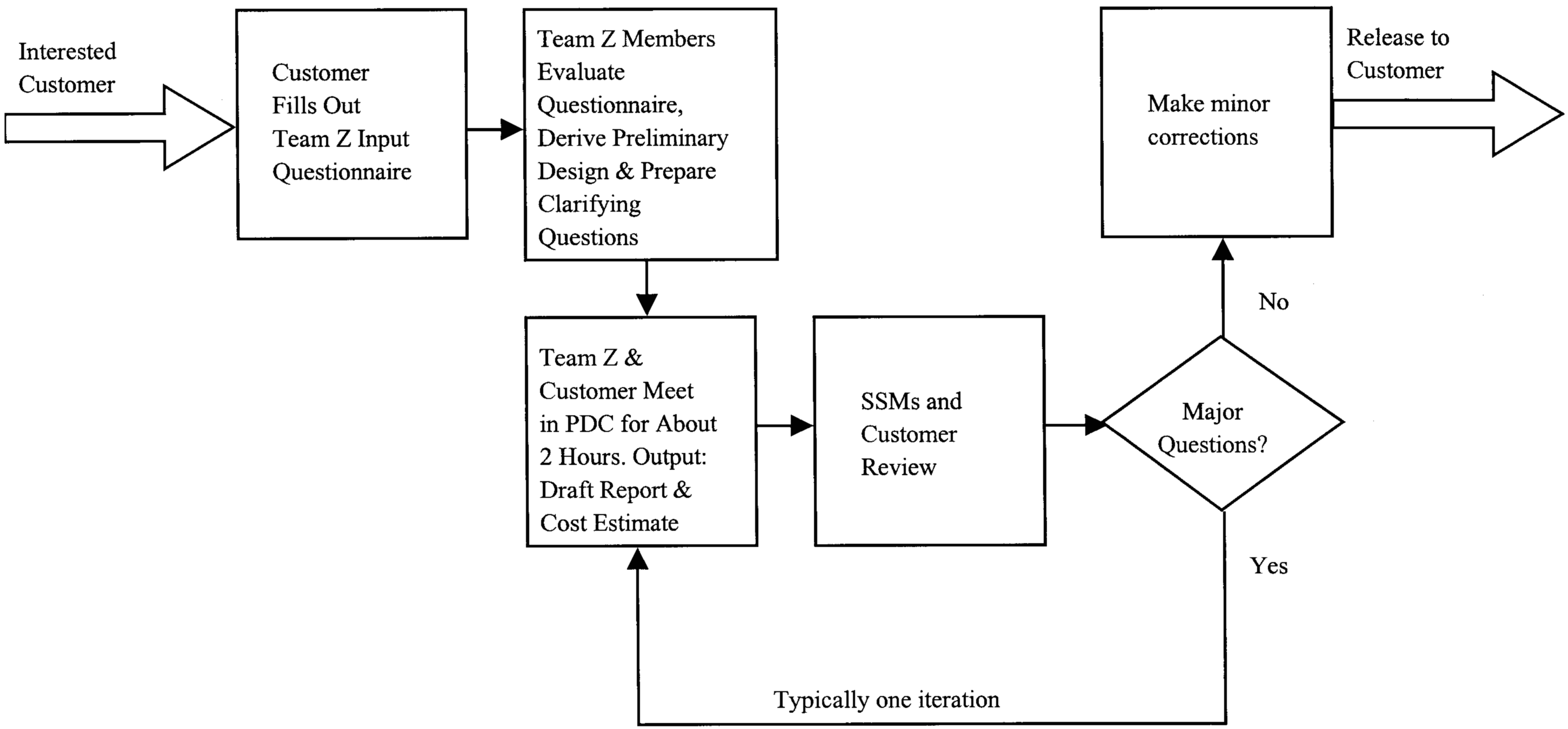
What is Team Z?

- Team Z is a concurrent engineering approach to designing and costing Mission Operations Systems. It involves three elements,
  - People
  - Process
  - Facilities and tools

Team Z Membership

Position	Frequency of Involvement
Facilitator	High
Documentarian	High
MOS Systems Integrator	High
Antenna & Microwave	Low
DSN Science	Medium
Flight Engineering	High
Science Instruments	Medium
Mission Services, Engineering	High
Mission Services, Operations	High
Network Infrastructure	High
Resource Allocation	High
Telecommunications & Data Mgt	High
Tracking & Navigation	High

Team Z Process



Team Z Facilities and Tools

- JPL Project Design Center
  - Linked workstations on JPL intranet, access to Internet
  - Teleconference capability
  - Collaborative applications available
  - Computer and viewgraph projectors
- Team Z tools
  - Input questionnaire
  - Linked spreadsheets
  - Collaborative report tool

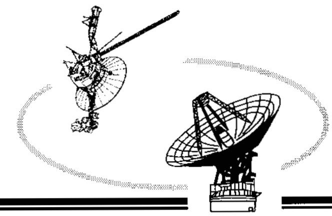
Sample of Team Z's Input Questionnaire

Mission Operations System Questionnaire		
Team Z Question	**Customer Answer**	**Default Question or Answer**
Mission Description:		
Describe your mission. Among the events to consider carefully are flybys, satellite tours, orbit insertions, entries, landings, rendezvous, body orbiting.	Overview:	Is your mission "like" another mission? Which one and in what way?
What solar system bodies will be visited and in what modes? (e.g., flyby, landing, orbiting)		
How many spacecraft are involved? Are we planning for a set of spacecraft or just one?		One
Describe any new technologies in your mission.		None.
Mission phases and duration (dates and days) *(For this purpose, a mission phase is defined as a length of time over which the tracking requirements are constant.)*		
What are the pre-launch events (key milestones)?		
Will there be Operational Readiness Tests?		Yes
. . .		
Assembly, Test and Launch Operations (ATLO)		
Duration (weeks)		
Where will ATLO be done?		JPL (SAF) and KSC
. . .		
Launch and post-launch checkout		
Duration (hours or days)		30 days
Tracking coverage requirements (actual tracking hours per pass, and passes per unit time)		3 eight-hour passes per day
. . .		
High-Activity Observational Period(s) (e.g., encounter)		
. . .		

Team Z Products

- Written report, containing:
  - Summary spreadsheets giving cost estimates by mission phase, for each service area
  - Sections describing each service, how and when it is offered, and the estimated costs
  - A COMPREHENSIVE STATEMENT OF THE ASSUMPTIONS THAT UNDERLIE THE SERVICES DESIGN AND THE COST ESTIMATES

- This report becomes the basis for a formal TMOD commitment to the project



Sample Team Z Summary Spreadsheet

JPL

	A	B	C	D	E	F	G	H	I	J	K
1	EXAMPLE MISSION										
2	IMPLEMENTATION PHASE SUMMARY	TOTAL		FY2001		FY2002		FY2003		FY2004	
3		WY	$K	WY	$K	WY	$K	WY	$K	WY	$K
4	Ground Communications		262.0		0.0		0.0	0.1	131.0	0.1	131.0
5											
6	DSN Radio Science		0.0								
7											
8	Instrument Science	5.9	944.9	1.3	212.5	2.3	393.5	1.5	196.2	0.8	142.7
9											
10	Mission Services and Applications	17.2	2928.4	2.1	345.6	4.7	801.0	5.7	980.3	4.7	801.6
11											
12	Basic MP&A Engr. Support	3.6	638.1	0.3	54.7	1.3	218.8	1.1	200.6	0.9	164.1
13											
14	Basic MS&A Operations Support	4.9	824.5	0.6	102.0	0.6	102.0	2.1	348.5	1.6	272.0
15											
16	FLIGHT ENGINEERING SERVICES	4.5	760.8	0.1	8.5	1.5	250.8	1.5	250.8	1.5	250.8
17											
18	MSAS ADAPTATION	4.2	705.1	1.1	180.4	1.4	229.5	1.1	180.4	0.7	114.8
19											
20	Navigation	3.8	637.5	0.0	0.0	1.3	212.5	1.3	212.5	1.3	212.5
21											
22	Development	3.8	637.5	0.0	0.0	1.3	212.5	1.3	212.5	1.3	212.5
23											
24											
25											
26	Telemetry, Command & Data Mgmt	5.9	985.3	1.0	167.0	2.3	384.1	1.5	250.5	1.1	183.7
27											
28	PROJECT ADAPTATION DEVELOPMENT	5.9	985.3	1.0	167.0	2.3	384.1	1.5	250.5	1.1	183.7
29											
30											
31											
32											
33	TOTAL DIRECT COST	32.7	5758.1	4.3	725.1	10.6	1791.1	10.1	1770.5	8.0	1471.4
34											
35	Resource Allocation (DSN Aperture Cost)										
36											
37	TOTAL ATTRIBUTED COST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38											
39	GRAND TOTALS	32.7	5758.1	4.3	725.1	10.6	1791.1	10.1	1770.5	8.0	1471.4
40		WY	$K	WY	$K	WY	$K	WY	$K	WY	$K
41		TOTALS		FY2001		FY2002		FY2003		FY2004	

Team Z Status and Future Directions

- Status
  - Team Z has been established as a formal part of JPL's proposal process
  - The process is substantially more efficient than past methods
    - Completing the questionnaire is arduous for the customers, but aids their proposal process by providing a rigorous, documented description of their mission operations needs
    - One brief (~15 minutes) presentation by the customer to Team Z
    - Two to four hours of joint meetings for *all* involved, replacing similar amounts of time for the customer to meet with *each* member
  - Collaborative tools are in place but need to be made more robust and easier to use
  - The elapsed time from receipt of customer's questionnaire to release of the final report is too long
- Future Directions
  - Improve Team tools and throughput
  - Improve capability for tradeoff proposals and analyses
  - Assist missions after the proposal phase, e.g., episodic evaluations or reevaluations for major reviews or design trades